

GROUND WATER HEAT PUMPS

A General Survey for the Potential Consumer

A Senior Thesis

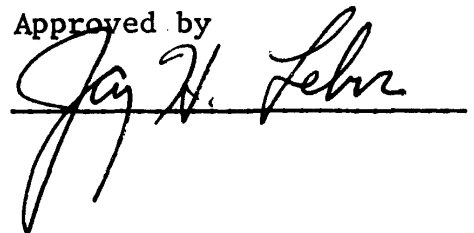
by

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ABSTRACT

This paper describes ground water heat pumps covering design, performance and alternative methods of use. Methods of water discharge are shown and discussed. Economic comparisons are made to other heat systems and recommendations given.

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INTRODUCTION

Ground water heat pumps are the most efficient method on the market for the conditioning of room air. The same unit can be used to heat and cool. Their use will become more and more common in the near future as alternatives to fossil fuel fired furnaces.

The general public knows little, if anything, about ground water heat pumps. The economic attractiveness of ground water heat pumps is luring consumers to this system.

Many special considerations are required for effective use of ground water heat pump systems. Often, two or more options are available for a single consideration. The consumer must be "educated" in order to choose the best option for the circumstances.

The purpose of this paper is to explain the options and define circumstances in which the options may or may not be used. This allows the consumer to make his own decisions, based on his needs and/or finances.

This paper explains the basic design of heat pumps, factors influencing their performance, alternative methods of handling ground water, and the comparison of the ground water heat pump to other systems of heating and cooling.

DESIGN AND FUNCTION

BASIC DESIGN

The principle of the heat pump has been around since 1824, when it was proposed by Nicholas Carnot. Lord Kelvin advanced the theory 30 years later, when he proposed that refrigerating equipment could be used to produce heat. Until the mid-1930's the heat pump remained in the lab. At that time, they began to be manufactured for comfort heating on a custom basis. In 1952, commercial production began and continues today with new vigor since the Arab oil embargo.

Consumers are generally not familiar with ground water source heat pumps, but they are familiar with air source heat pumps. Air source heat pumps are used in refrigerators and freezers to remove heat from the inside of the unit and place the unwanted heat outside of the unit. Air source heat pumps are used by the average air conditioner to cool our homes. They are used widely in the South, known as air-to-air heat pumps.

Ground water heat pumps have a distinct advantage over their air-to-air heat pump cousins. Ground water heat pumps use water instead of air. Heat pumps transfer heat from one place to another. Heat is transferred to or from the water (or air) through a medium to or from inside air. The advantage of water is that it allows this transfer more efficiently than air. More efficient heat transfer means less work is required to transfer the heat and this relates directly to energy cost savings. Water has a specific heat 1.0 and the specific heat of air is approximately 0.2. Specific heat is the number of Btu's required to raise one pound of a substance one degree

Fahrenheit. This means that water can store and give up five times as much heat as an equal mass of air. Water has one of the highest specific heats of any common substance, making it an excellent heat source and sink. Water may also be used in the system at a constant temperature, which allows for the most efficient operation. Outside air, on the other hand, is subject to a range of temperatures.

The transfer medium commonly used is Freon, a registered trade name of the E. I. DuPont De Nemours Company. Other refrigerants may be used, such as ammonia and nitrogen. Figure 1 shows a heat pump operating in the heating cycle. Liquid Freon enters the water-to-refrigerant heat exchanger. Being colder than the water, the Freon picks up heat from the water, raising its own temperature and lowering the temperature of the water five to ten degrees Fahrenheit. As this is done, the Freon evaporates and becomes a warm gas. Then it enters the compressor and leaves at a higher pressure and temperature, where on some systems it may provide heat for domestic hot water supply from 140 to 180 degrees Fahrenheit. The still hot gas proceeds to the finned heat exchanger, where room air is heated from 105 to 120 degrees Fahrenheit and ducted through the building. The now condensed Freon as a liquid passes through the expansion device, where pressure and temperature are reduced. The cycle is now complete and starts again. Operation of the system is controlled by a wall thermostat, like conventional heat systems.

In the cooling mode (Figure 2) of reversing systems, (not all systems are so equipped) the hot pressurized Freon from the compressor enters the domestic hot water exchanger, if present. During the cooling mode, domestic hot water is truly heated free with the "unwanted" heat removed from

FIGURE 1
The Heating Mode

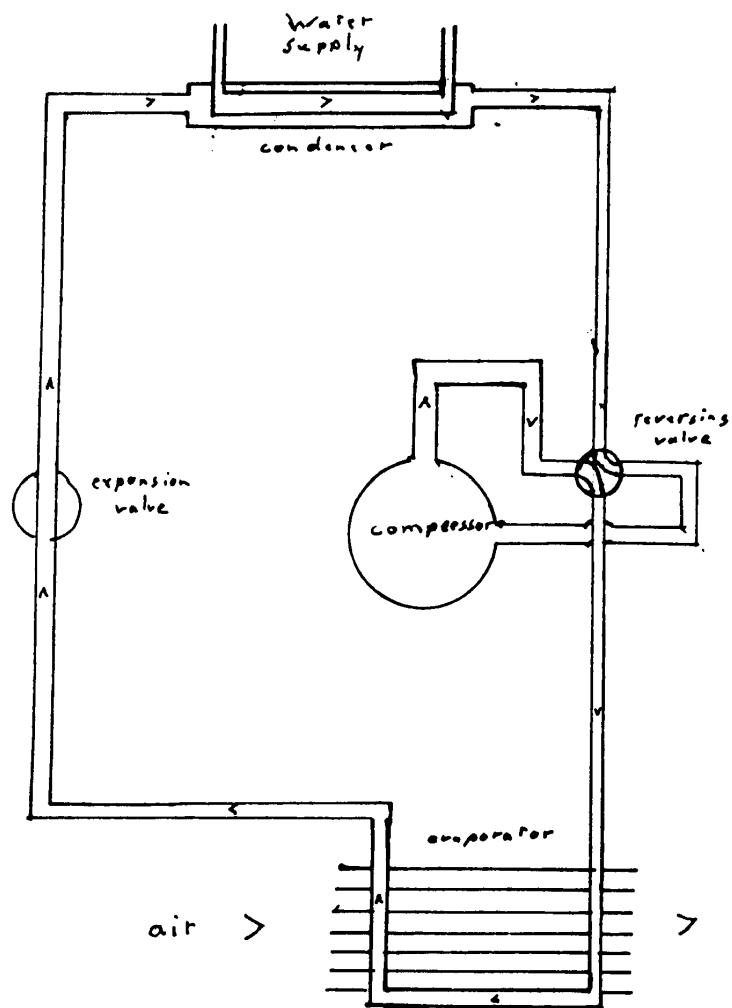
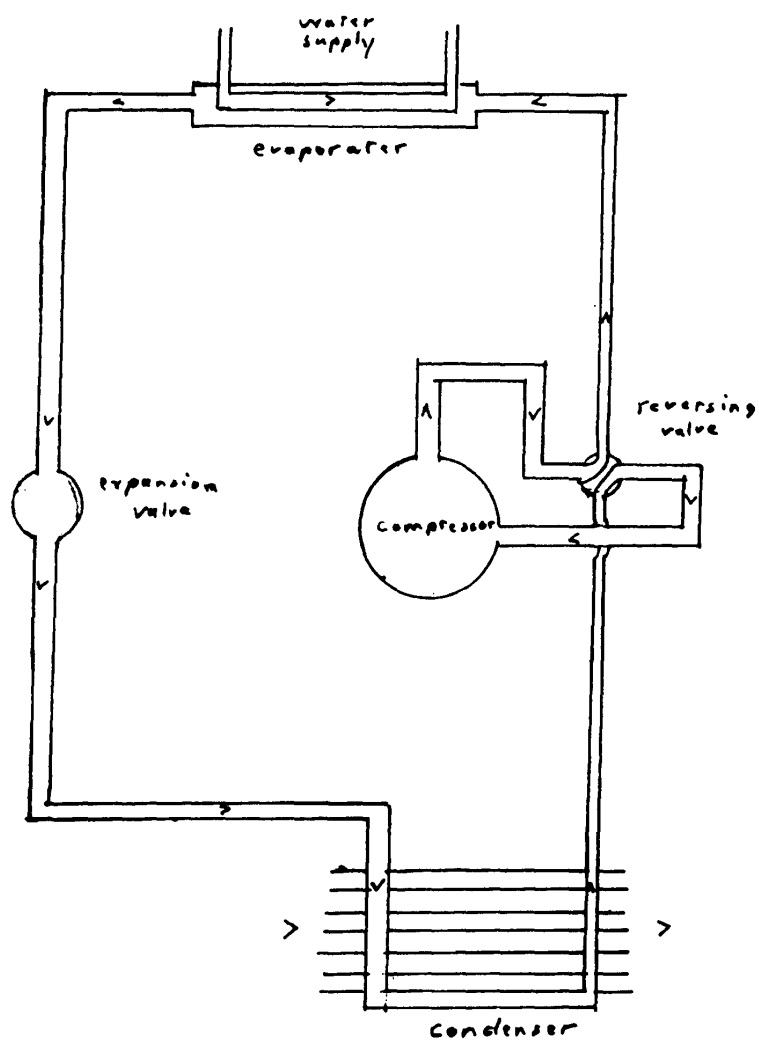


FIGURE 2
The Cooling Mode



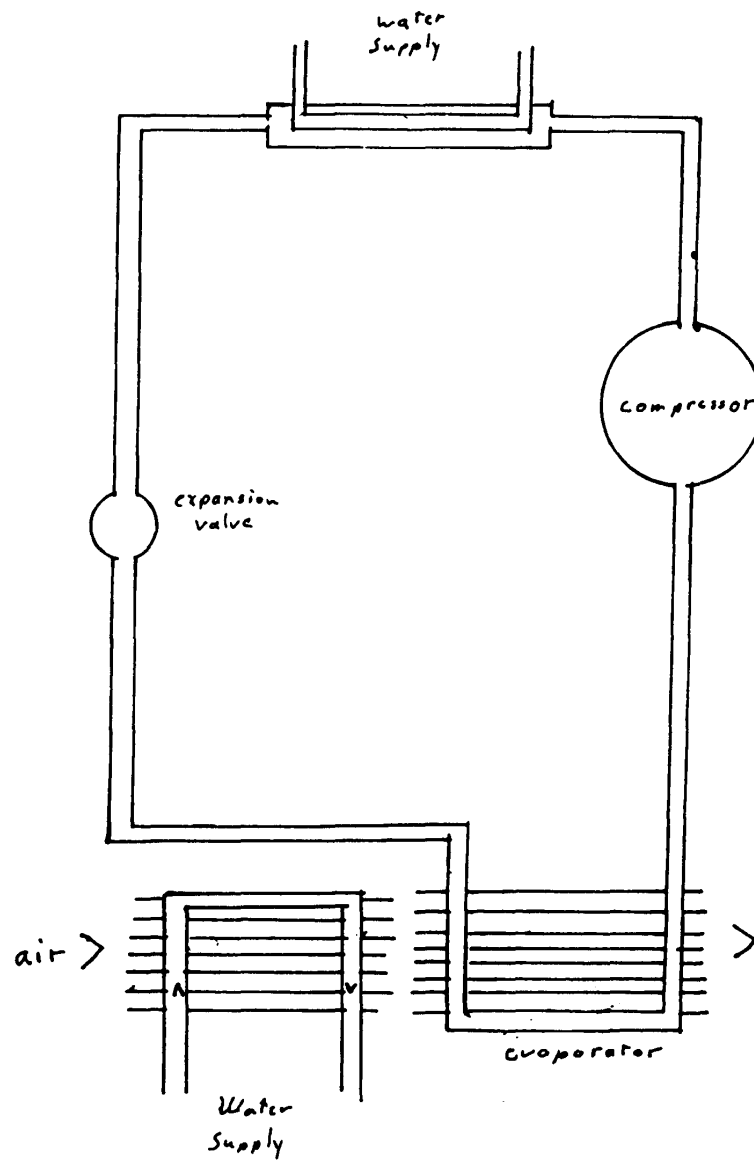
room air. The still hot gas is directed to the water-to-refrigerant heat exchanger. Heat is transferred to the water, which is warmed five to ten degrees Fahrenheit. The gas is condensed to a liquid, which passes through the expansion device, reducing pressure further. In the finned heat exchanger, the liquid expands to a gas, transferring heat from the room air, which is cooled ten to twenty degrees Fahrenheit. This completes the cycle as the gas enters the compressor.

In both of these modes, water is not consumed or polluted. It simply provides an efficient heat source or sink.

Some systems use direct water cooling (Figure 3) with a heat only heat pump. A water-to-air heat exchanger provides direct cooling of room air. This is done by passing room air over finned coils, which contain cool flowing water. The manufacturers do this to save using the compressor and reversing valves, the latter of which may stick or wear out. Only small amounts of energy are used by the water pump and blower fans, the latter of which is required on all central air conditioning systems. The result is added energy efficiency. However, the free heat for domestic hot water supply is lost. This loss is not quite as great as it seems. Systems using a domestic hot water loop heat water only when the unit is running and only for free in the cooling mode. When the heat pump is not running or is unable to supply heat demands for the domestic hot water, electric resistance must be used to supplement the system. Thus, the mode that is in use and actual time spent running determine the amount of free hot water produced.

Ground water heat pumps are composed of six essential components, and three optional components. The compressor is usually a reciprocating model, in residential systems with a crankshaft, rods, and pistons to compress the

FIGURE 3
Direct Cooling



Freon. The motor and compressor are hermetically sealed in a single shell. The first advantage of this is a simplified seal without moving parts that pierce the seal, which may cause leaks. The second advantage is the motor may be cooled by the Freon.

An air-to-refrigerant heat exchanger is the condenser in the heating mode and the evaporator in the cooling mode. The air-to-refrigerant heat exchanger is typically composed of copper tubes, which Freon circulates, and thin aluminum fins for greater surface area, thus more heat transfer.

The water-to-refrigerant heat exchanger is the evaporator in the heating mode and the condenser in the cooling cycle. Typically, they are coaxial (tube in a tube) with water in the inner tube and Freon in the outer tube. However, some are made with a coil of tubing in a shell. The inner tube should be cupro-nickel tubing, for use with ground water.

The expansion device can be of three types. The first type and simplest is a capillary tube, which is a small bore tube used as a fixed restriction. The second type is an automatic expansion valve, which maintains a constant evaporator pressure. The third type is a thermal expansion valve, which regulates flow for optimum conditions for the evaporator. The valves have proven to work better in field conditions, especially the thermal expansion valve when a range of water temperatures are to be used.

The blower is usually a direct drive fan to draw return air and blow it over the air-to-refrigerant heat exchanger or direct cooling coil.

Freon is the usual refrigerant, which by boiling at low temperatures improves heat transfer.

The reversing valve is solenoid-operated valve, which pistons to change

the ports of connecting lines; this reverses the flow between the compressor and heat exchangers.

The two optional components are backup resistance heat and the domestic hot water loop.

PERFORMANCE

The performance or efficiency of heating systems are rated by the Coefficient of Performance (COP). The COP is the heating or cooling output divided by the energy input. It is the percent of the energy used by the system that actually goes toward heat or the heat removed in cooling. A heating system with a COP of .7 delivers 70 percent of its energy requirements as useable heat output. It is the high average COP of ground water heat pumps that makes them competitive with fossil fuel systems.

The temperature of the water used as a source or sink affects the efficiency of the system. The higher the entering water temperature, the higher the efficiency will be. Table 1 shows the heating capacities of a unit using nine gallons per minute (GPM), 70 F entering air, and variable temperatures of entering water. Ground water heat pumps can use the full temperature range of ground water in the continental United States, as shown in Figure 5.

Another major factor influencing the COP is the flow rate of entering water. Low flow rates can result in a low COP. Figure 4 shows test results of the effects of the COP of a unit by varying the flow rate.

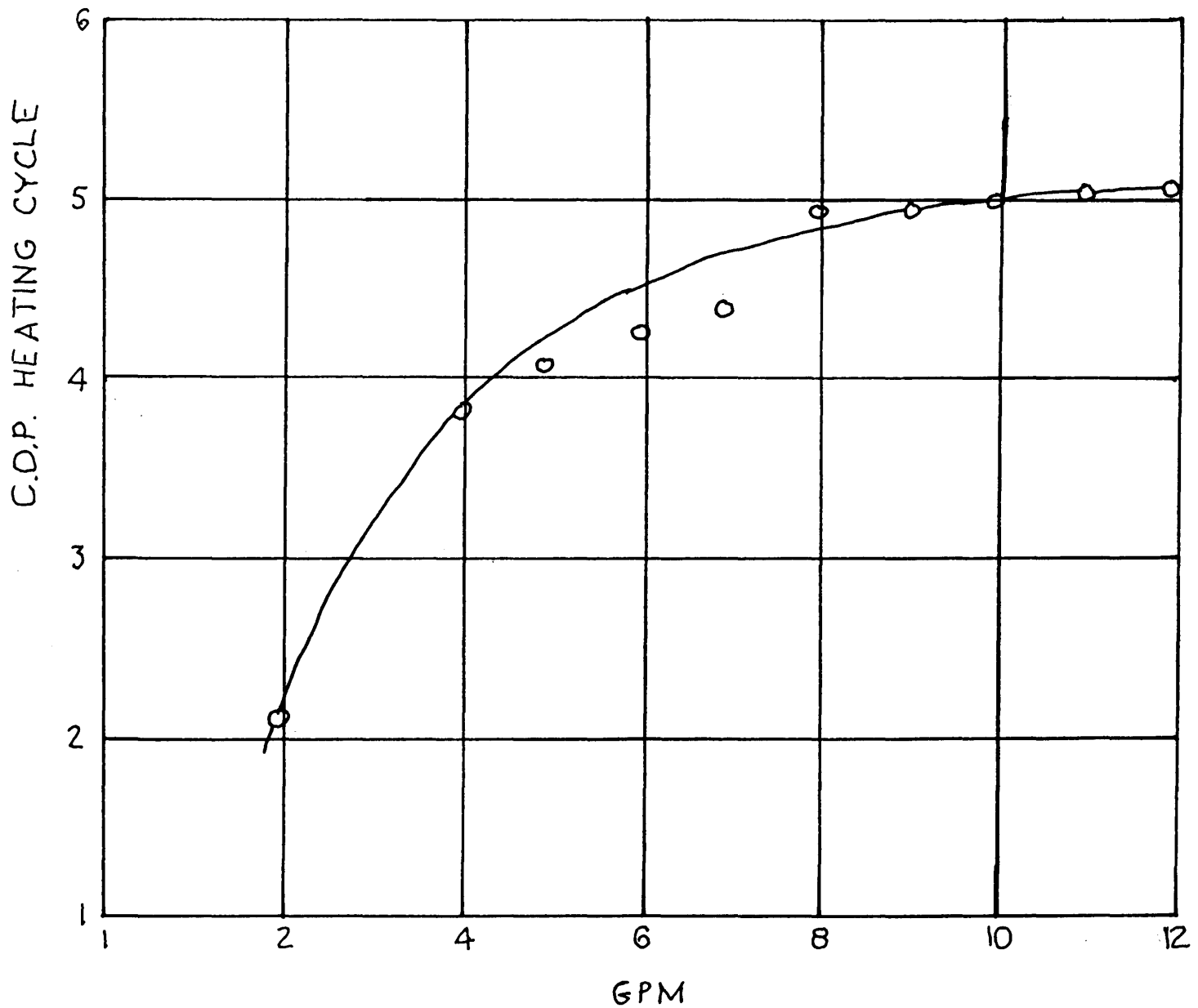
The heat capacity of a unit may have to be lowered in northern climates to prevent freezing in the unit. This can be compensated for by raising the flow rate, thus the COP. The average well-insulated home requires twice the

TABLE 1
 Heating Capacity (BTU)
 vs.
 Entering Water Temperature (EWT)
 (Heating with 70 Entering Air Temperature)

<u>GPM</u>	<u>60 EWT</u>	<u>65 EWT</u>	<u>70 EWT</u>	<u>75 EWT</u>
9	34,000	35,400	36,800	38,000

Source: Ground Water Heat Pump Journal, Spring, 1980

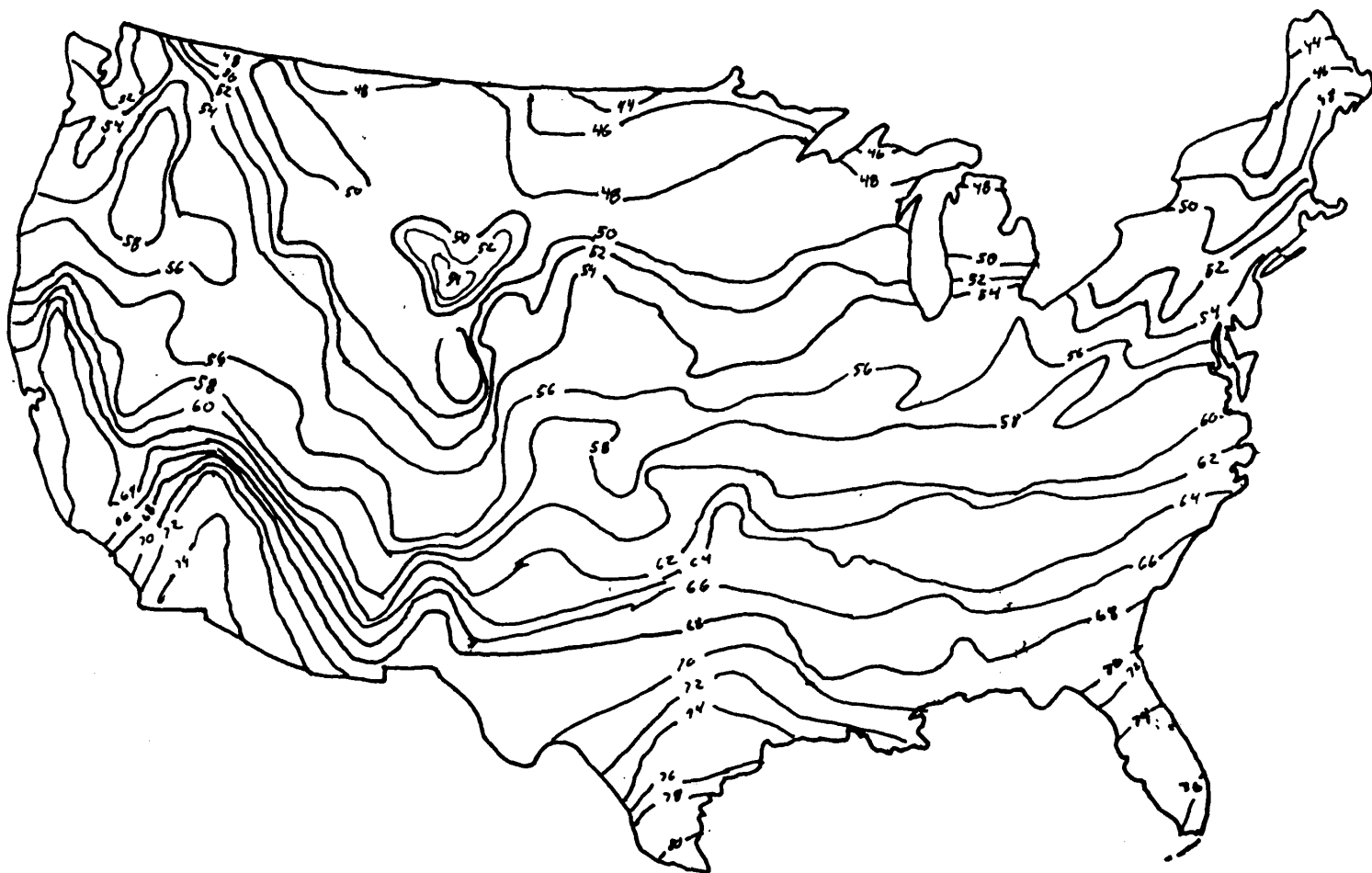
FIGURE 4
COP vs. Flow Rate



Data points from the Louisiana State University, 1980, using a 4½ ton heat pump and using well water at 73° F.

FIGURE 5

Average Temperature of Shallow Ground Water



Note: Numbers on lines are in degrees Fahrenheit.

Source Data: Ground Water Heat Pump Data by Franklin Electric

flow rate, using 40° F water, than the 6.0 GPM needed using 60° F water. As a rule of thumb, ground water heat pumps require 2.5 to 3.0 GPM as a minimum for every 12,000 Btu per hour needed for heating or cooling. One manufacturer reports that with 55° F water, the company's 36,000 Btu unit needs 2.5 to 3.0 GPM/12,000 Btu (1 ton). The same unit, with 50° F water, requires 5.0 GPM per ton and 10.0 GPM per ton with 45° F water.

The temperature and rate of air moving through the unit also has an affect on the COP. Ground water heat pumps only heat return air to 100 to 110° F compared to conventional systems which put out 140° F air. As a result, in order to achieve the same results the blower on ground water heat pump must circulate larger volumes of heated air to do the same job. The results are larger supply and return ducts to handle increased volumes of air. A more powerful fan with average size ducts would make the rooms feel drafty and would lower the efficiency of the unit.

Corrosion and scaling produced by the water can form a layer of insulation on metal surfaces within the water-to-refrigerant heat exchanger. This prevents effective heat transfer and lowers the COP of the unit. This is why the inner tube containing ground water should be made of cupro-nickel. Ground water corrosion will be reviewed separately further on.

GROUND WATER

THE ENERGY SOURCE

Ground water source heat pumps are often called ground water geothermal heat pumps. The latter is a partial misnomer. The main source of heat for surface water temperatures is solar. Another name could be ground water solar heat pumps. The sun is the primary source of heat for the earth's surface. A portion of this heat is stored in ground water and rock bodies making the earth a large natural solar collector. The insulating properties of the earth keep the ground water temperatures from varying by more than a few degrees through the year. The National Water Well Association in a study for the Department of Energy showed that temperatures of shallow ground water (50-200 feet) normally are just slightly higher than mean air temperatures. This is demonstrated in Figure 5, in which a general north-south gradient can be recognized. These slightly higher temperatures are due to the geothermal gradient from the earth's molten interior. Thus, the source of heat in shallow ground water is a mixture of geothermal and solar energy.

It is easy to imagine how ground water and the subsurface could be used as heat sinks; they feel cool to the touch. Ground water and the subsurface, through the use of heat pumps, can be seen and realized as a heat source too. Ground water is a heat source that is renewable and efficient, thus attractive.

ENERGY TRANSFER METHODS

The water-to-air heat pumps transfers heat to and from room air, to or from water. This water leaves the unit, depending on the mode in use,

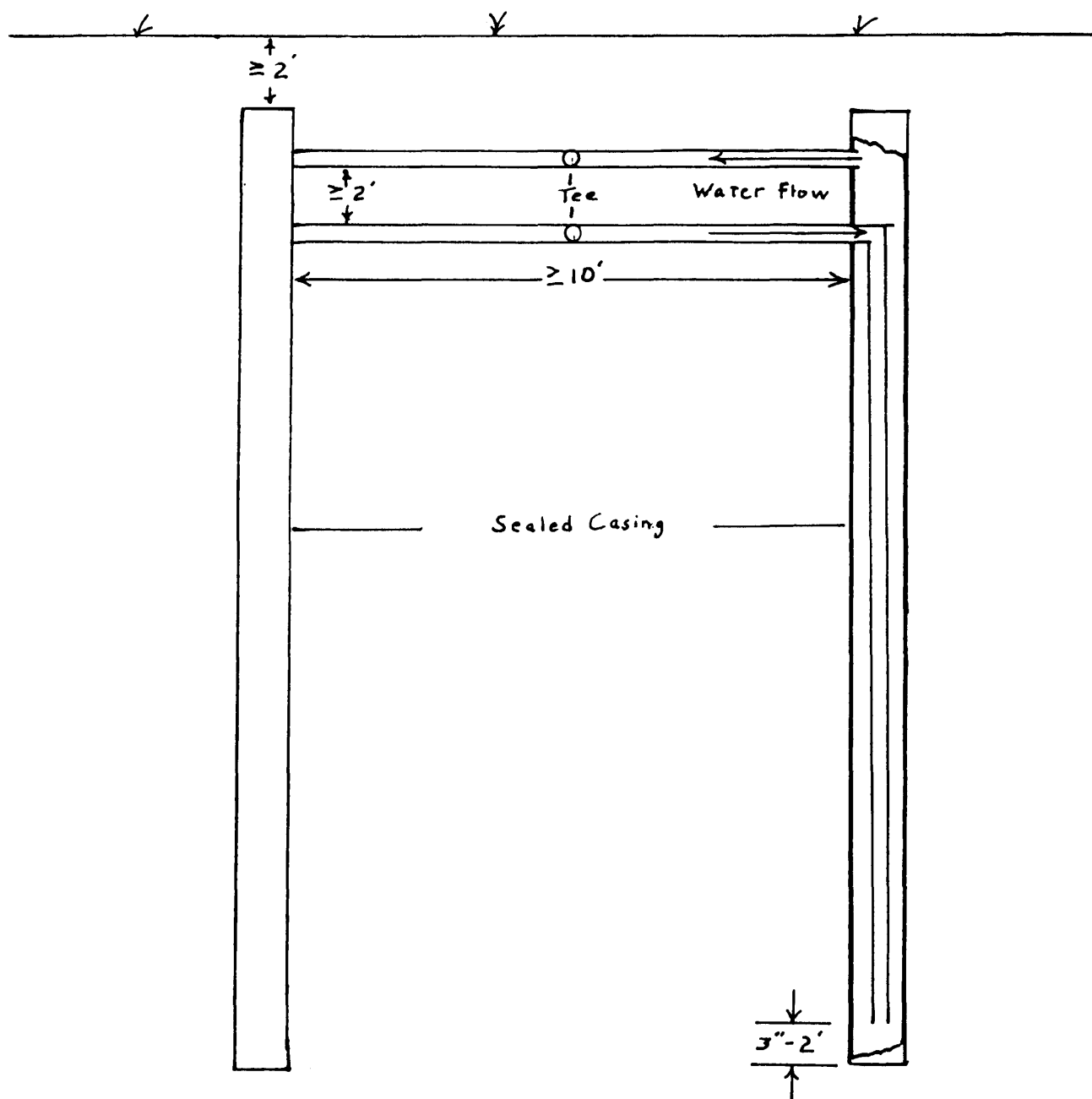
warmer or cooler than the surroundings it came from. Thus the water must carry out its "own" energy transfer to remove the temperature gradient between the water and its surroundings after leaving the heat pump.

Two basic methods have been devised to use ground water and the subsurface as heat sources and sinks. They are the closed loop earth coupled system and the open well system. The closed loop earth coupled systems can be one of two general types. The first is the vertical heat exchanger (or geothermal well) and the other is the horizontal heat exchanger (or earth coil). Both systems circulate water mixed with antifreeze, usually 10-25 percent by volume of propylene glycol U.S.P., through a continuous closed-loop within the earth and through the heat pump by using a small pump.

A vertical heat exchanger, installed by a well driller, is shown in Figure 6. It consists of a sealed casing, which is capped and sealed at both the top and bottom. Two adapters are located near the top, one allows water from the heat pump to enter the casing. There it flows rapidly down the dip tube to near the well bottom. The water then travels slowly up the exchanger, exchanging heat with the earth. Near the top, the water leaves the exchanger and returns to the heat pump for another cycle.

System requirements may dictate a greater well depth than is practical to drill. In such cases, two or more exchangers may be connected in series (if head losses are not too great) or in parallel to achieve heat exchange requirements of the system, such as in Figure 6. Well depth is a function of heating or cooling load dominance, Btu load, climate, and geographic location. In Oklahoma, vertical exchangers used successfully, are constructed with 100 feet of wetted casing per ton of heat pump capacity.

FIGURE 6
A Vertical Heat Exchanger



Some recommendations for vertical heat exchangers by James R. Partin follow.

Depth of Dip Tube - The dip tube should extend no closer than three inches from the bottom and no farther than three feet. This allows maximum heat exchange, while allowing clear flow.

Well Spacing - Wells connected in series or in parallel should be at least ten feet apart to minimize thermal interference.

Casing Packing - Casing not packed above the aquifers is useless for heat exchange.

Cleanliness - Care should be taken to keep earth and trash out of the casing during installation. The exchanger should be flushed before connection with the heat pump.

Service Lines - Service line should be buried at least four feet deep and kept separated by two feet for insulation.

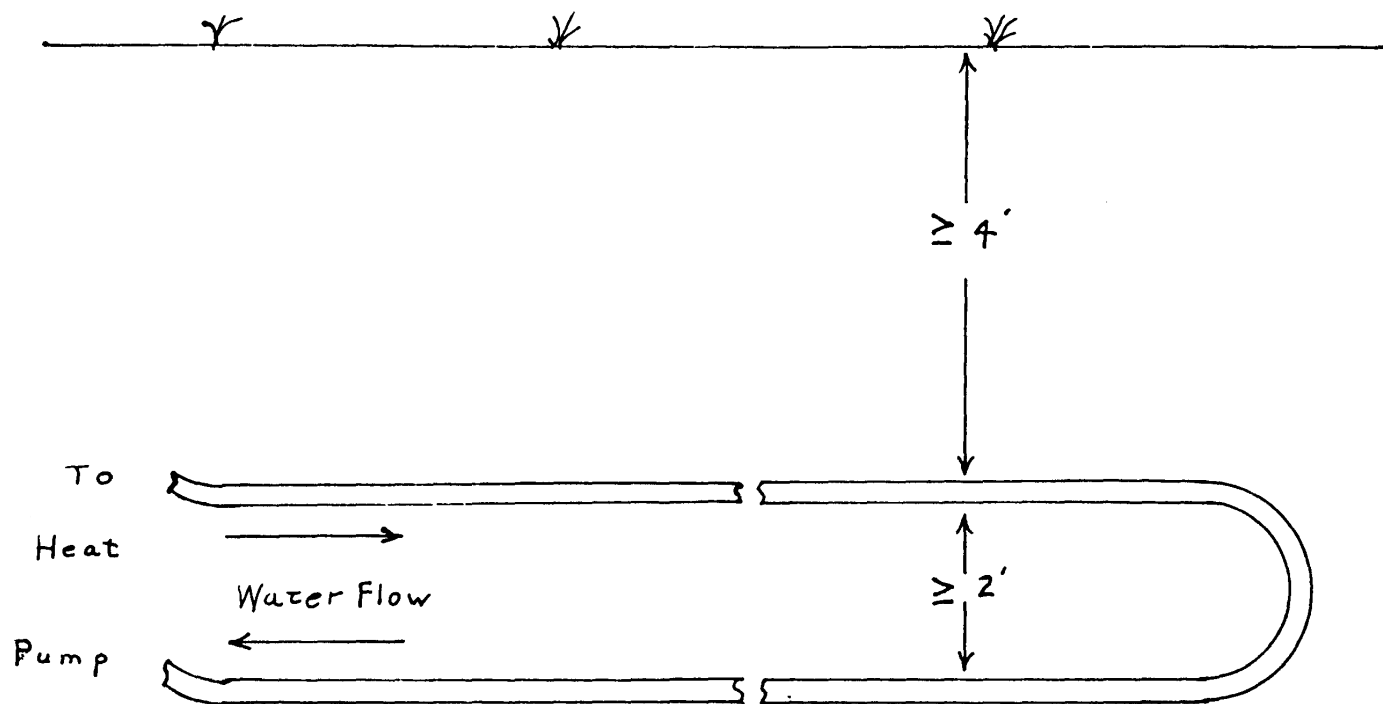
Parallel Exchangers - The depth of the exchangers shall be within five percent. Branch service lines shall tee from a main line and shall be within ten percent of each other in length. This is to maintain equal head and prevent "shorting" of water through one well, lowering efficiency.

The horizontal heat exchanger commonly consists of a plastic tube leaving the heat pump buried at least four feet deep and a return tube buried at least six feet deep in the same trench as in Figure 7. Heat exchange takes place with the earth, as the water passes through the tube and back again. Like the vertical heat exchanger, two feet of separation between the tubes is called for. The tubes may be in equal parallels, if needed, similar to paralleling in vertical exchangers.

The same care should be taken to insure cleanliness, also.

With the deepest tube carrying water into heat pump, the heat pump is provided with the coldest water in the summer and the hottest in the winter. Return water temperatures may vary from 30° F in the winter to 100° F in the summer. This large temperature range is beyond the capacity

FIGURE 7
A Horizontal Heat Exchanger



of many heat pumps on the market. However, James R. Partin reports a mid-winter COP (performance is better in the fall and spring) of 2.8 in northern climates for such a system.

The length of the coil per ton of heat capacity in Oklahoma is 300 feet of wetted tubing or 450 feet of dry tubing. The length of the coil is a function of heating or cooling load dominance, Btu load, geographical location, soil conditions, and climate.

Open well systems also can be one or two basic types. Those that can supply the heat pump with enough water and those which can not, and must store water for peak demand. The National Water Well Association (NWWA) in a 1976 study, reported that 75 percent of the continental United States has adequate water resources, with proper management, to use ground water heat pumps for residential heating and cooling. If water storage is utilized an additional 10 percent of the continental United States is now suitable for residential ground water heat pump utilization. When an adequate water supply is available for a heat pump and probable domestic use, that water is simply pumped from a well. The pump supplies the water at the required flow rate for the water's constant temperature and the unit's Btu load.

This well is usually required to supply a home's daily non-heat pump water consumption. The average per capita consumption is 70 gallons a day. A family of five would have an average water usage of 350 gallons each day. A five ton heat pump, which requires a flow rate of 15 GPM and runs 50 percent of the time during peak demand uses over 10,000 gallons of water per day. This represents quite an added demand on a well, that without a heat pump would be required to produce less than 400 gallons per day.

Coverage of water disposal methods are to follow.

WELL DEVELOPMENT

A well supplying a ground water must be capable of supplying an adequate amount of water for the heat pump, during its greatest heating load (a long cold spell), and the household demand. The household demand during peak could be as high as the demand for the heat pump alone. Many existing wells may not be developed to meet such a demand. If a ground water heat pump is to be added to an existing well, the well should be tested to see if it will produce adequate supplies of water. Testing procedures are to follow.

If a new well is to be drilled the first step is to determine the capacity of the pump to be used. The assistance of a knowledgeable contractor is recommended for pump sizing.

The second step is to determine size of the casing, in which the pump is housed. The diameter of the casing is, in general, one to four inches larger than the pump bowls or suction devices to be placed in the well.

The third step is to drill the well. When a water-bearing strata (an aquifer) is reached it may be tested to determine if the yield is adequate. Aquifer yield is a function of permeability (the ease movement of water through the aquifer) and the thickness of the aquifer.

The fourth step is the pump testing of the well. All wells should be tested, since an aquifer can vary in permeability from place to place. Comparison to nearby wells can be misleading.

The three part testing procedure recommended by Jim Poehlman, the director of technical services for the NWWA, is to follow. First certain terms should be defined.

Static Water Level (SWL) - the depth to water in a well not pumped for at least 24 hours.

Pumping Level (PL) - the depth to water in the well during pumping.

Drawdown (DD) - the difference between the SWL and PL.

Specific Capacity (SC) - the yield of a well expressed in gallon-per-minute for each foot of drawdown.

The first part is the constant rate test. Water is pumped at $1\frac{1}{2}$ times the flow rate to be required by the heat pump. Water level is then measured: one a minute for 10 minutes; every 5 minutes for the next 50 minutes; every 10 minutes for the next 90 minutes and then every hour for the next $4\frac{1}{2}$ hours or until the water level stabilizes.

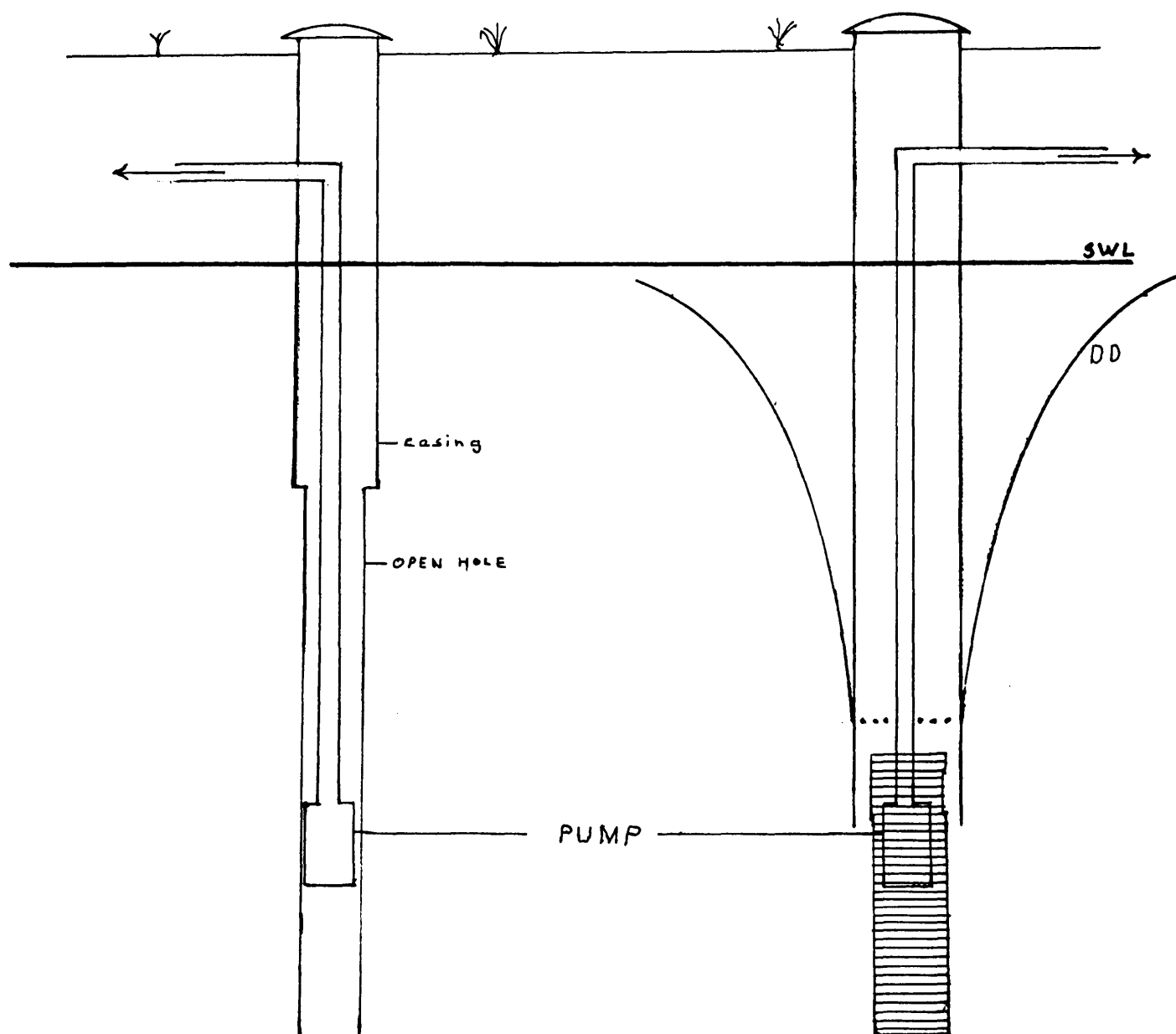
This part of the test determines the drawdown, the area affected by the well (which is important for spacing other wells), and the level at which pump should be set below, see Figure 8. If the water level does not stabilize, options such as water storage or deeper drilling should be considered. If the pump should stop during this part, proceed to the second part.

The second part is the recovery test. The pump is shut off and the water level is measured: each minute for 15 minutes; each 10 minutes for the balance of the first hour; each hour until the water reaches the starting level.

This recovery test should mirror the constant rate test, to verify the results of the constant rate test.

The third part is the step test. The well is pumped at 25 percent of flow rate used in the constant rate test until monitoring of the water level shows that the water level has stabilized. After stabilization or a minimum of 30 minutes the pumping rate is increased 25 percent and the procedure is repeated again until the flow rate is $1\frac{1}{2}$ times the rate to be required by the

FIGURE 8
A Supply Well



heat pump. When the water level has stabilized the total drawdown can be found.

The step test is performed to find the well's efficiency or specific capacity. The specific capacity is calculated by dividing the flow rate by the draw down.

The fifth step is the proper developing of the well, whether it can meet the yield requirement or water storage is needed. Further construction may be needed, such as a well screen to prevent sand from entering the water supply. Well screens vary in design and cost. In general, the cost is reflective of the quality. To reduce corrosion or incrustation of the screen, the velocity of entering water should not exceed 0.1 feet per second, yet allowing the desired amount of water to enter the well.

As a last step the driller will mechanically develop the well. This includes removing all fine material and drilling fluid, which lowers well efficiency.

When the demand of the heat pump and domestic needs exceeds the well yield, one of four water storage methods may be used.

A larger well may be able to store the extra water needed. Deeper wells, even though no other aquifers are encountered, are full of water to the top of the aquifer. The extra depth stores additional water. Larger well diameters may also store additional water, while providing larger contact with the aquifer. A larger area of the aquifer in contact with the well will provide a larger yield.

A pressure tank, which insures adequate water pressure and avoids frequent pump starts, may provide small amounts of additional water when demand temporarily exceeds supply.

A large non-pressurized storage tank under ground or in the basement can be used when the flow rate required by the heat pump exceeds the well yield.

The principle is the same as that used by toilets and flush tanks. A large storage tank requires its own pump to supply water to the heat pump alone (to comply with health codes). Tank sizes varies with Btu load, climate, conventional water usage, and water well yield.

The following equation can be used in sizing the tank.

$$V = P (H \times M - (W \times M - C))$$

Where: V = the volume of the tank in gallons

P = the percent of the day the heat pump will operate
under peak demand

H = the heat pump's required flow rate in GPM

M = the number of minutes per day

W = the water well yeild in GPM

C = the conventional water usage in gallons per day

Using this equation a home having: a heat pump that will run 8 hours a day; a heat pump flow requirement of 12 GPM; a well yielding 8 GPM; and conventionally uses 480 gallons a day would need a 2,100 gallon tank. This size tank could supply the heat pump's flow rate when demand is greater for several days. A larger tank than that calculated will be needed if conventional water usage might increase.

Storage requirements and water usage can be reduced by recycling the water leaving the heat pump back into a tank equipped with an overflow. During light Btu load of fall and spring, the tank may be the only source

of water required by the heat pump. During heavier Btu loads, water temperature in the tank is controlled by thermistors, which control the addition of make up water from the well. Valving in the system should allow flow to the heat pump directly from the well and flow of water from the heat pump to a discharge system.

DISCHARGE ALTERNATIVES

Little has been mentioned thus far regarding the handling of water that has passed through a heat pump. The volume of water could be 10,000 gallons a day on some days for a single home. Clearly the handling of such volumes requires consideration. From a conservation point of view, the water should be returned to the aquifer or put to an alternative use. The importance of conserving ground water resources has been known for years in coastal areas, such as Long Island and the west coast. Enough fresh ground water was removed to allow salt water infringement in normally fresh water zones. Maintenance programs through the use of recharge wells and ponding have brought the infringement under control. Although ground water constantly being renewed by the hydrologic cycle. Care must be taken not to exceed the capacity of this cycle. Ground water heat pumps are becoming and will continue to become more numerous, this dictates a need for intelligent decisions concerning aquifer recharge with water used by ground water heat pumps. Common disposal and recharge methods are: secondary use; surface discharge; horizontal wells; shallow, large diameter wells; and small diameter recharge wells.

Secondary uses, such as industrial process applications, agricultural uses, and auxiliary plumbing for lawn and garden watering comply with conservation measures and are economical. However the quality of the water, which

may be acceptable to the heat pump, could limit secondary uses.

Surface discharge methods include ponding, and discharge into sewers, lakes, streams and the ground surface. Ponding advantages are: economical construction; possible scenic, recreational, and wildlife value; and water conservation. Disadvantages of ponding are: higher water tables; property area losses up to two square feet per gallon of discharge each day; possible maintenance requirements (to maintain infiltration rates); incomplete aquifer recharge (due to evaporation); and not necessarily recharging the supply aquifer, which may be separated by impermeable strata from a higher aquifer. Discharge into sewer lines may cause lines to back-up or benefit from the "flushing" action. Partial recharge may result from discharge into lakes and streams. However wildlife may be harmed by thermal effects or lower quality water, which also would contaminate the stream or lake. Discharge on the ground surface may: create bogs; increase pollutant leaching into ground water; increases sinkhole activity; and forms icy areas in the winter.

The horizontal disposal well, as illustrated in Figure 9, consists of a gravel packed well screen. Cost of the system is a function of screen length, which is a function of soil type and maximum daily discharge. The system is most efficient in sandy soils where each foot of screen length can handle 300 gallons of water. Clayey and silty soils require a 600-foot screen to handle the same amount of water. This limits the system to use with sandy soils. The system is subject to plugging and is difficult to rehabilitate. Like surface disposal methods, the horizontal disposal well may cause local water table rises and may not recharge the supply aquifer.

Shallow large diameter wells (Figure 10) when properly designed, can be

FIGURE 9

A Horizontal Disposal Well

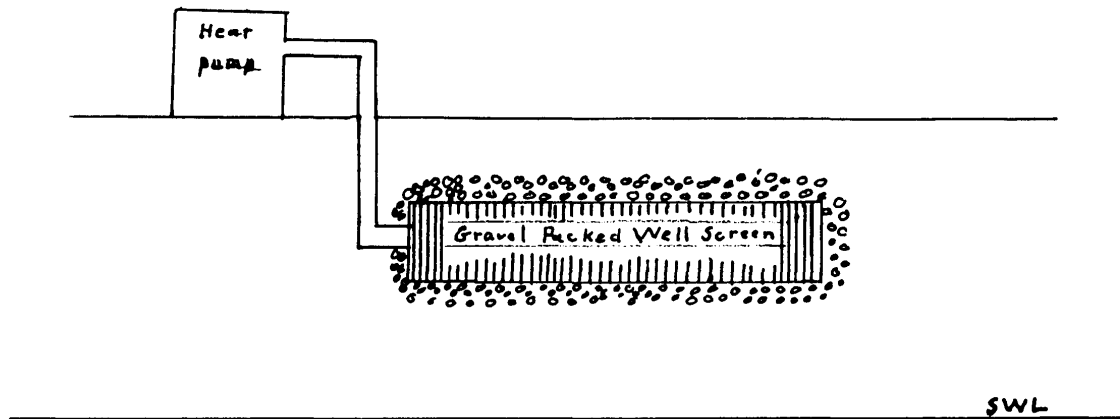
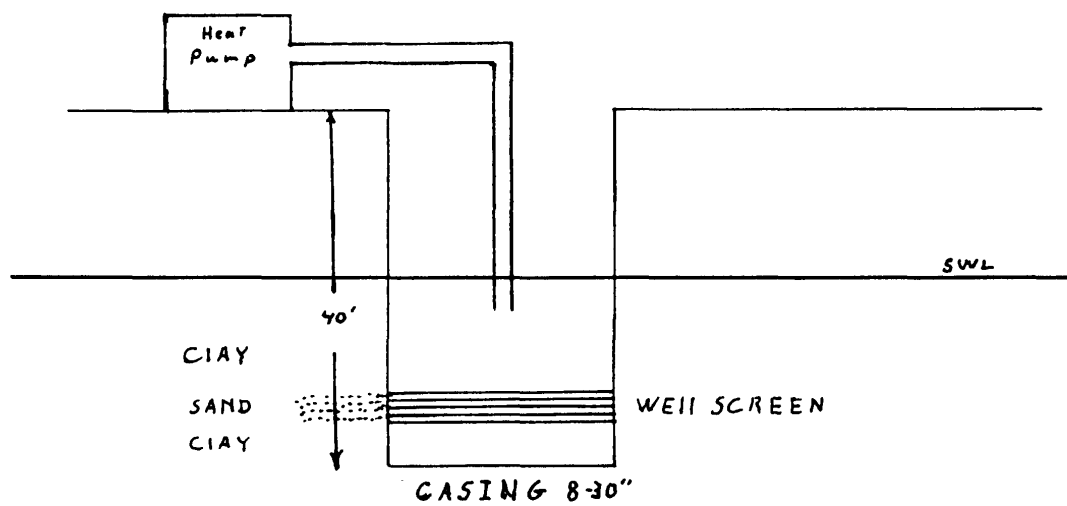


FIGURE 10
A Shallow Large Diameter
Disposal Well



good disposal systems. This system works well with shallow and thin (one to two feet) layers of fine sand. Gravel packed well screens may or may not be required. The system is economical to install, has easy access for maintenance, a large storage capacity, and could also supply water. Again, like the previous systems, geologic conditions may not allow recharging of the supply aquifer.

Small diameter recharge wells are constructed like the supply wells shown in Figure 8, except that the water flow is reversed and they do not contain a pump. Like supply wells, they may or may not use a well screen. Their construction may include a pump so the two wells can be used interchangeably with additional plumbing. Reasons for this will be discussed later.

Small diameter recharge wells are the most common water disposal method for ground water heat pumps. The reasons for this are: the return of water to the supply aquifer for maximum conservation; minimal water table uplift with more permeable layers; easy to maintain (good response to acidization and rehabilitation); and possible alternative use as a production well.

Five important factors must be considered for recharge well use. These factors are: clogging of the well and aquifer; the accepting capacity of the recharge well; thermal interference with the system's supply well; coordination of wells with aquifer conditions; and changing the temperature of the water in the aquifer.

Clogging of the aquifer or recharge well may not become obvious until the well overflows unless recharge volume, pressure, and level

are monitored. Six common causes of recharge well clogging listed by Gass, 1981, are reviewed below.

1. Incompatibility of indigenous ground water and recharge water may cause precipitation of iron oxides, calcium carbonate, and silica compounds due to temperature differences.

2. Ion exchange between the recharge water and clay particles may cause the particles to disperse and become lodged in aquifer pore spaces.

3. Aeration of recharge water can provide oxygen for precipitation of iron compounds on the screen. Entrained air can become lodged by molecular attraction in pore spaces, blocking water flow.

4. Bacteria, which may be present in the aquifer, and their metabolic products reduce pore space and permeability.

5. Reversing water flow can result in the mechanical jamming of aquifer particles, which can reduce pore volume and permeability.

6. Suspended sediments in the recharge, which reduces pore volume and permeability, is the most common cause of loss of recharge capacity.

Aeration can be reduced by use of diaphragm-type pressure tank and termination of the injection tube below the static water level with a check valve. The check valve prevents the water from draining out of the injection tube when the heat pump is not running. If the tube drains, air will be injected into the well when the heat pump starts up.

Reversed flow jamming effects are minimized in a properly designed and constructed well.

The two well alternation system may work as preventive maintenance by preventing clogging of the well screens when used.

Rehabilitation generally consists of mechanical surging, and pumping a dispersing agent (sodium hexametaphosphate) and disinfectant (chlorine) into the well. The well is then pumped to remove the chemical and dispersed particles.

The accepting capacity of an aquifer, theoretically, will equal the maximum yield. However, it will only accept 75 to 80 percent of its maximum yield in recharge. This means the recharge well construction must equal or surpass that of the supply well.

When water is injected into a recharge well, a reversed drawdown cone will be formed. This results in a water level above that of the static water level. This is known as the injection head.

The height of the injected head, above the static water level, is a function of well construction, injection rate, aquifer permeability, and screen or borehole losses. This height can be approximated using the known specific capacity and injection rate. The injection rate divided by the specific capacity is the theoretical height of the injection head. For example, if the injection rate is 20 GPM and the specific capacity is 0.5 GPM per foot drawdown, the water level will rise 40 feet. This assumes that the efficiency of the well has remained unchanged. Allowances should be made for well deterioration and the water level should never rise to the frost line.

Thermal interference, from inadequate spacing of the supply and recharge well, would lower the efficiency of the heat pump. This threat exists due to the 5 to 10° F temperature change of water passing

through the unit. Increases in inlet temperatures during the cooling mode cause the heat pump to work harder to transfer heat into a warmer heat sink. Reverse conditions during the heating mode also result in lowering unit efficiency, thus raising operating costs.

The spacings required to prevent thermal breakthrough of a single water particle has been tabulated (Kazmann and Whitehead, 1980) for twin wells. This was done using Marx-Langenheim equations by assuming: a spacing; an actual pumping/injection ratio (flow rate multiplied by the percent of operating time during the critical season); aquifer porosity (percent of water volume in the aquifer); aquifer thickness; and the heat capacity of rock and water. This produces a time period for the thermal breakthrough. This was repeated for different aquifer characteristics and the results tabulated (see Table 2). Actual spacing requirements are likely to be lower since the heat lost to the confining strata is not accounted for.

Location and spacing of wells will most likely depend on property boundaries. In urban areas, this random installation may cause well interference (overlap of drawdown cones which lowers yields) and thermal interference. Coordination, through planning and study of aquifer conditions, can prevent well interference and allow optimum heat dissipation in the aquifer.

In some regions, where only one mode of the heat pump is required, the ambient temperature of the ground water may be changed. In the South, this would result in a lower cooling efficiency. In the North, danger of freezing in the heat pump could limit heat pump use or at least lower

TABLE 2
Required Spacing Between Twin Wells*
(Porosity = 20%)**

		Critical Period (days)		
		100	140	210
A q u i f e r	T			
	h			
	i			
	c			
	k			
	n			
e e s s	e			
	e			
	s			
	s			
	10'	114'	127'	145'
	20'	98'	109'	127'
	30'	86'	100'	117'
	40'	79'	94'	108'
	50'	72'	83'	99'
	80'	55'	70'	83'
	100'	55'	65'	78'

*For a five-ton heat pump with a 20 GPM throughput and an actual rate of 10 GPM over the critical period.

**For a porosity of 10%, multiply the spacing by 1.05; for 30% porosity, multiply by 0.95.

Source: Kazmann and Whitehead, 1980

heating efficiency. Most areas will be able to maintain a heat balance in the aquifer by using both modes during the year.

WATER QUALITY

Water quality is usually not a serious problem and won't interfere with ground water heat pump installation. Most problems can be prevented with choice of plumbing materials.

Nearly all ground water produces "fouling", a thin coating of oxides on the inner surface of the water tubes in the water-to-refrigerant heat exchanger. This results in a slight insulation of exchangers, which can be overcome by overdesign. Extended surface-to-refrigerant heat exchangers should not be used because they rely on a clean water-to-metal contact.

Calcium carbonate (CaCO_3) scale can also insulate the exchanger. Scaling usually occurs during the cooling mode. When temperatures increase in the water, CaCO_3 is precipitated out as scale. This is corrected when the heat pump is reversed, which dissolves the scale by increasing solubility of CaCO_3 in lower water temperatures. CaCO_3 solubility also increases with higher pressures. Higher pressures in the system can be maintained by the injection tube check valve. In cases of high CaCO_3 concentrations, acid flushing is needed for regular maintenance.

Corrosion concerns with ground water are usually of the following three types:

1. Galvanic - This is the creation of an electric cell, generated by an electric ground on the water line, which corrodes the higher of the two metals connected

on the electromotive series. This can be avoided by selection of plumbing metals and nonconductors to isolate the heat pump from domestic electric grounding.

2. Dezincification - Zinc is leached from the copper matrix in brass. This can be prevented by the use of plastic fittings and valves.

3. Geochemical - This is usually the presence of hydrogen sulfide, which can corrode the standard cupro-nickel tubing with as little as 0.5 ppm. Stainless steel tubing instead of cupro-nickel is the cure.

Knowing the quality of the water in advance can make a big difference in the choice of plumbing materials.

EFFICIENCY AND ECONOMICS

WELL COST

Figure 11 displays ten major water regions for the continental United States. Since geologic conditions may vary widely within a region, well depth averages for each region are stated. Variations between regions are due to major geologic structures and geologic history.

Well costs depend not only on well depth, but local geologic structures such as mountains, valleys, and plains. For example, drilling costs in mountain hard rock will exceed the cost for drilling into sand and gravel aquifers of valleys. These sand and gravel aquifers will usually be at shallower, less costly depths.

COST COMPARISONS

Table 3 lists the common types of heating systems in use today. The table is a guide to calculations, which show the cost of each system during its lifetime.

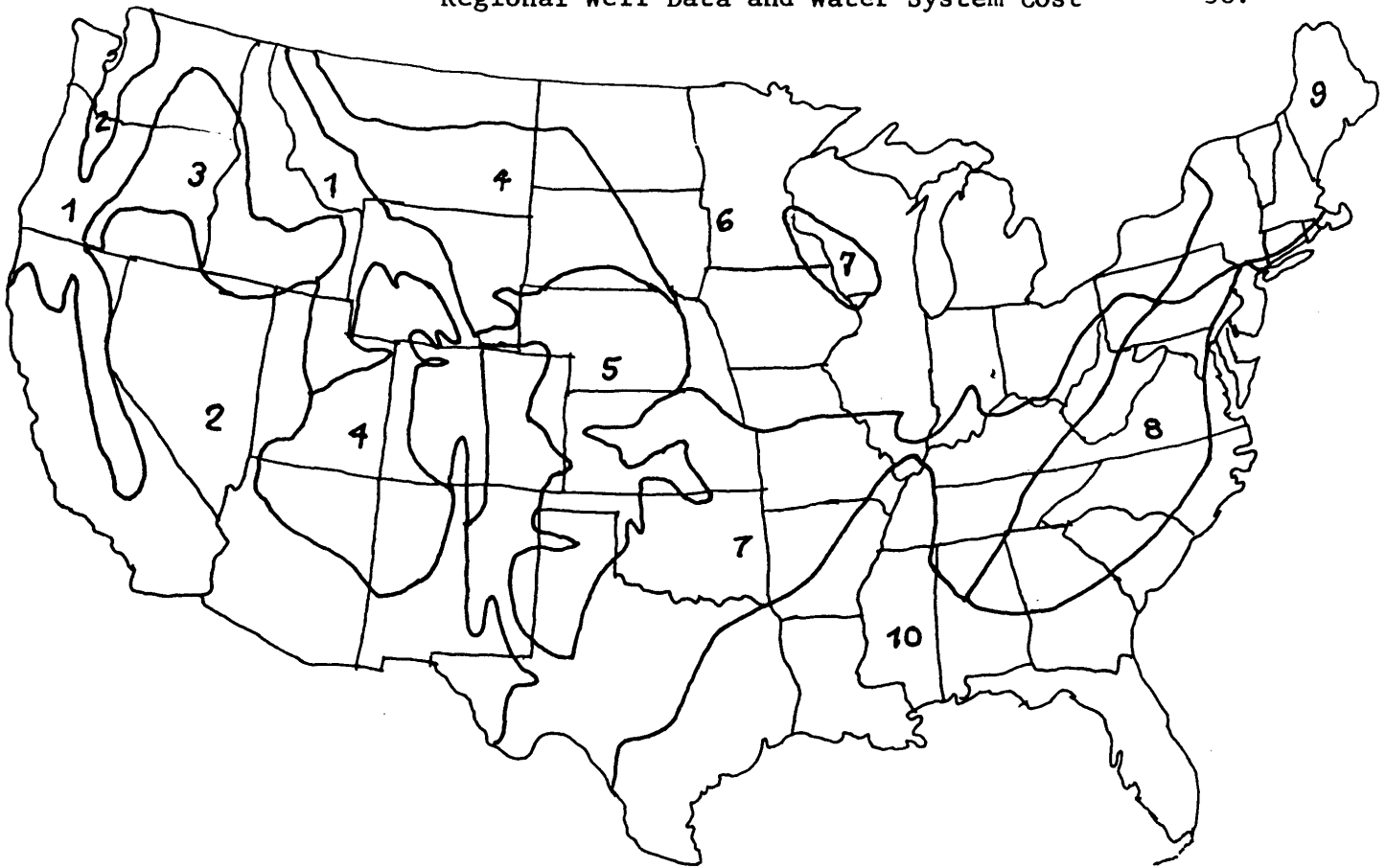
Calculations up to and including annual heating costs are for a particular example, thus being accurate guidelines. After this point, estimated costs defray accuracy. However, it can be clearly seen that the ground water heat pumps require less energy spendings than other systems. This is due to their high COP. Fossil fuels are continuing to escalate in cost much faster than electricity. This will widen the gap further.

The main drawback to ground water heat pumps is that they have the highest initial cost among the tabled systems. This initial cost could be considered greater than that shown.

FIGURE 11

Regional Well Data and Water System Cost

38.



Ten Major Ground Water Regions	Average Well Depth	Cost to Drill Average Well	Total Well Cost Range*
1	250	\$3770	\$2000-5000
2	400	6188	2600-7000
3	200	3042	1550-6000
4	300	4029	2000-5000
5	300	1458	1250-5000
6	150	1680	1250-3750
7	200	2058	1550-4000
8	250	2600	2350-6000
9	100	1385	1150-3750
10	75	640	1250-3250

* 1978 NWWA Water Survey

Average cost for well and pumping system for 10 GPM - \$2400-2800.

Average cost for cased well only - \$1600-2000.

Average well depth is 200 feet.

Source: Ground Water Heat Pump Data by Franklin Electric

TABLE 3

Cost Comparisons

	Gross Heat Content	Useful Heat Content	Fuel ² Cost	COP
<u>Fuel Oil</u>	140000 BTU/gal	91000 BTU/gal	120¢/gal	.65
<u>Propane</u>	91169 " "	63812 " "	71.38¢/gal	.70
<u>Electric Resistance</u>	3415 BTU/kwh	3414 BTU/kwh	4.19¢/kwh	1.00
<u>Natural Gas</u>	95000 BTU/th	66500 BTU/th	35¢/th	.70
<u>Air-to-Air Heat Pumps</u>	6830 BTU/kwh	6380 BTU/kwh	4.19¢/kwh	2.00
<u>Ground Water Heat Pumps</u>	56700 " "	56700 " "	4.19¢/kwh	3.44 ²

¹ 7 GPM, 50 F, 1/3 hp pump included

² Northern Indiana cost, Feb., 1981

	Annual Fuel Needs	Annual Heating Cost	Estimated Cooling Cost	Estimated Hot Water Cost
<u>Fuel Oil</u>	1000 gal	\$1231 ⁴	\$150	\$400
<u>Propane</u>	1426 "	\$1039 ⁵	\$150	\$400
<u>Nat. Gas</u>	1368 th	\$ 500 ⁶	\$150	\$400
<u>Air-to-Air Heat Pumps</u>	13324 kwh	\$ 559	\$150	\$400
<u>Ground Water Heat Pumps</u>	7747 kwh	\$ 324	\$ 90	\$200
<u>Electric Resistance</u>	26663 kwh	\$1118	\$150	\$400

TABLE 3 (continued)

	<u>Total Energy</u> <u>Cost</u>	<u>Initial</u> <u>Cost</u>	<u>Unit Life</u> <u>(years)</u>	<u>Life Cycle</u> ⁹ <u>Cost</u>
<u>Fuel Oil</u>	\$1781	\$3000 ⁷	20	\$38620
<u>Propane</u>	\$1588	\$2700 ⁷	20	\$34460
<u>Electric</u> <u>Resistance</u>	\$1667	\$2500 ⁷	20	\$35840
<u>Nat. Gas</u>	\$1049	\$2500 ⁷	20	\$23480
<u>Air-to-Air</u> <u>Heat Pumps</u>	\$1108	\$3500 ⁷	20	\$25660
<u>Ground Water</u> <u>Heat Pumps</u>	\$ 874	\$5200 ⁸	20	\$22680

7 with central air

8 including one \$2200 well

9 initial cost and fuel cost for
20 years (unit life)

Source Data: Ground Water Heat Pump Systems

Question and Answers for the Consumer by NWWA

Ground Water Heat Pump Data
by Franklin Electric

Even cooling costs are considerably lower than that of other systems. The South need not be excluded from saving money.

All systems are listed as having a life expectancy of twenty years. This will hold true reasonably well except for the air heat pump. Its life span could be half of what is listed.

The estimates of cooling costs and hot water costs are the major sources of error. The errors should not alter the life cycle cost by more than 10%.

Natural gas presently is the only system which offers competition to ground water heat pumps. Since the fuel price escalation of natural gas is the highest, and electricity is the lowest, this competitiveness will soon disappear.

Tax incentives offered on the state level would reduce the life cycle cost of a ground water heat pump system. Further, incentive may be forthcoming from national government.

RECOMMENDATIONS

The first step of a prospective ground water heat pump consumer should be consultation with a knowledgeable contractor. There he will learn more about ground water heat pumps and decide if it is feasible or not. Many contractors provide free audits to determine heat pump capacity, if retrofitting duct work or added insulation is needed, and to show cost comparisons with other heating and cooling systems.

If a ground water heat pump is to be used, a test of water quality should be performed. This could prevent problems later.

Well capacity will need to be known to determine if water storage will be needed and to find the amount of storage dictated.

Finally, the discharge type will be decided. The National Water Well Association recommends the alternating recharge/supply method or secondary use.

The winter/summer two well method returns water to supply aquifers the best and takes fuller advantage of aquifer conditions.

If lawn or garden watering is to be used, additional plumbing to allow this should be added as a partial discharge method or a full discharge method for commercial agriculture.

I personally recommend that all homeowners planning construction that includes a well for domestic water supply investigate ground water heat pumps. The same applies to those replacing spent conventional furnaces.

A great potential exists for use and return of city water at lower

meter rates. This would benefit the urban dweller and municipalities, who would receive "free" income. Study should be conducted to determine if this is feasible on a large scale.

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